Concepts for Realizing the 2017 NRC Decadal Survey Recommendations for Surface Deformation and Change Observables

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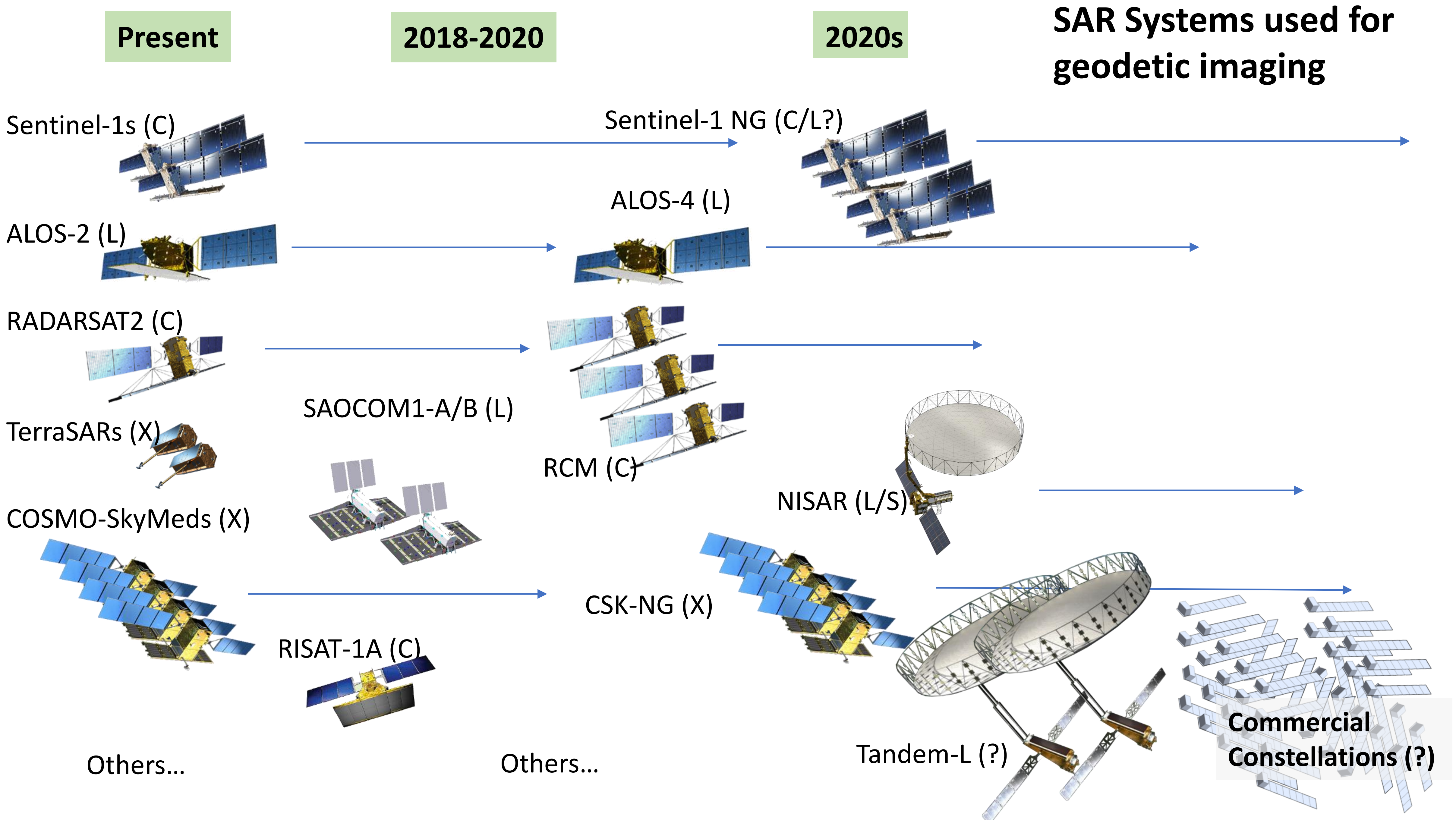
2017 Decadal Survey
Land Surface Deformation Requirements for Different Science Objectives

			Time Series	
Objective	Spatial resolution	Precision	Frequency	Duration
S-1a	**10 m**	**10 mm**	**event-dependent**	
S-1b	**10 m**	**10 mm**	**12 days**	**10+ yr**
S-1c	50 m	1 mm/yr	< seasonal	
S-2a	**10 m**	**10 mm**	**event-dependent**	
S-2b	10 m	1 mm/yr	event-dependent	
S-2c	100 m	1 mm/yr	event-dependent	5+ yr
S-3a	**100 m**	**10 mm/yr**	**< seasonal**	
S-3b	**<50 m**	**5–10 mm**	**weekly**	**10+ yr**
S-4a	**<5 m**	**5–10 mm**	**weekly**	**10+ yr**
S-5a	100 m	10 mm		
S-6a	5 m	10 mm	weekly	
S-6b	5 m	3 mm/yr	weekly	
S-7a	5 m	10 mm	weekly	

”hours to days”

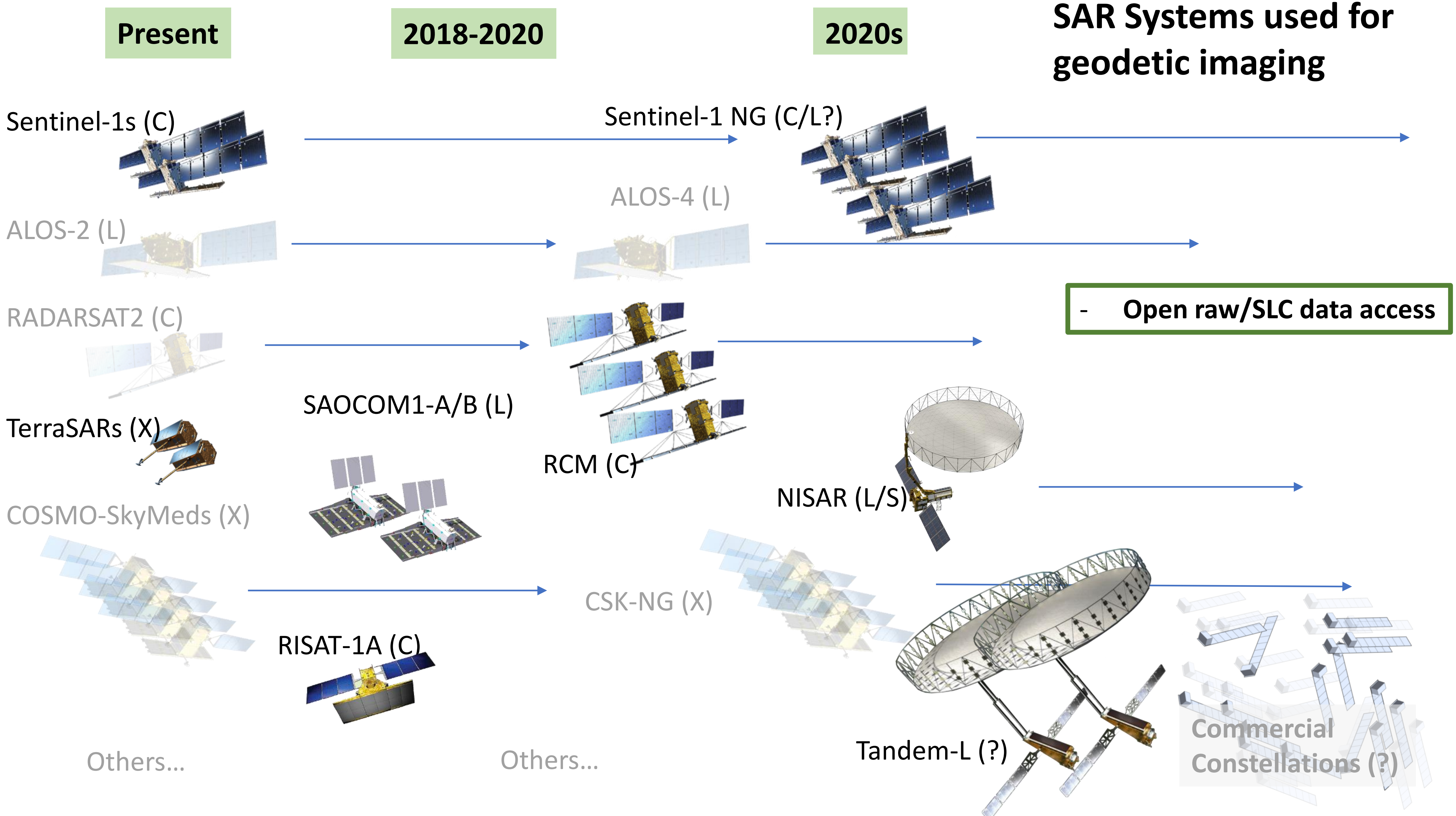
Requirements for the Most important objectives are marked in bold.

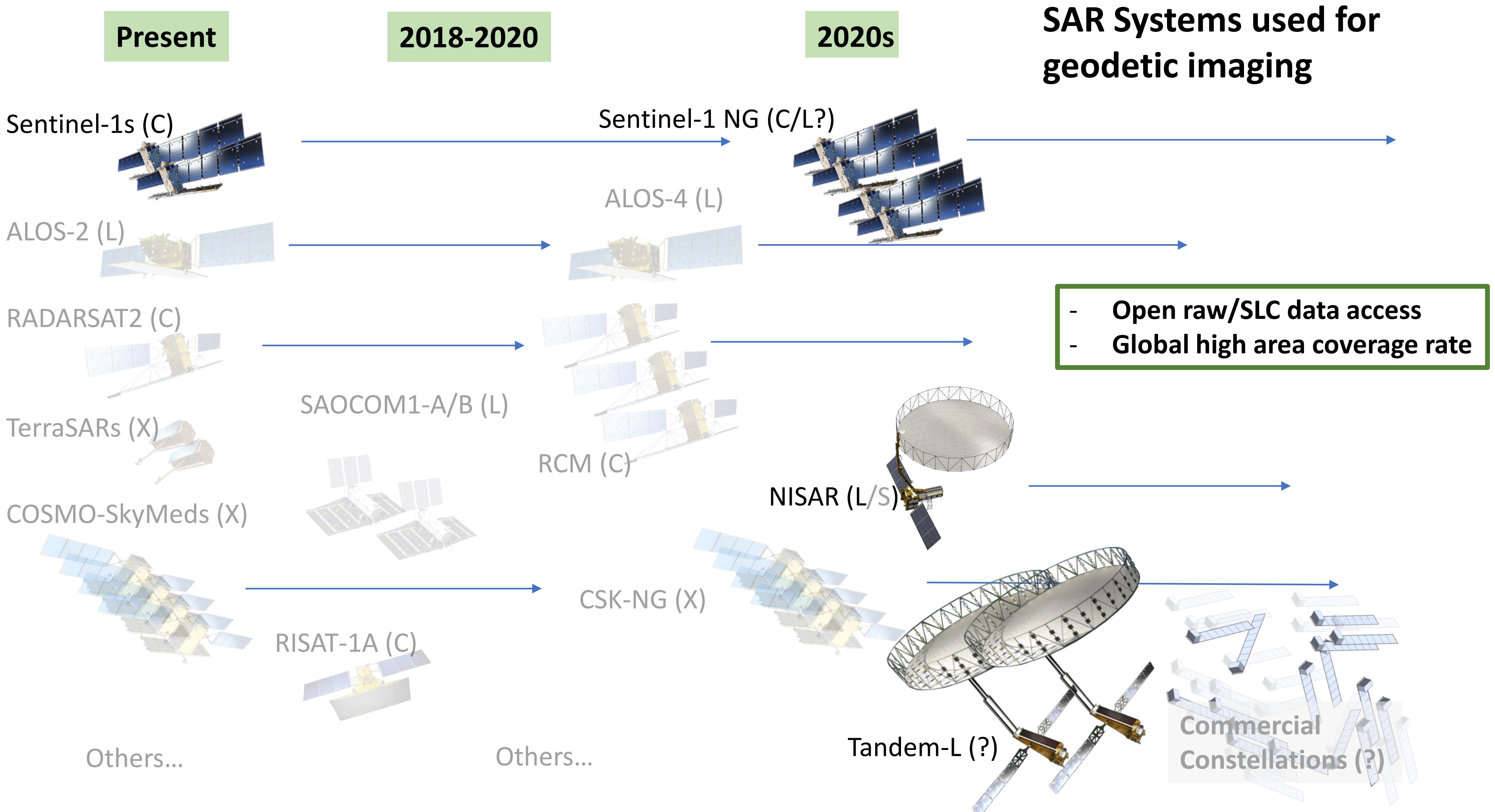
Explicit: event dependent objectives are in the “most important” category, and entail sub-weekly sampling
Explicit: $500M cost to NASA (Phase A-D)
Implicit: Measurements can be made anywhere, at any time



SAR Systems used for geodetic imaging
Present
2018-2020
2020s
Sentinel-1s (C)
Sentinel-1 NG (C/L?)
ALOS-2 (L)
ALOS-4 (L)
RADARSAT2 (C)
RCM (C)
TerraSARs (X)
SAOCOM1-A/B (L)
COSMO-SkyMeds (X)
CSK-NG (X)
NISAR (L/S)
RISAT-1A (C)
Tandem-L (?)
Commercial Constellations (?)
Others...
Others...

SAR Systems used for geodetic imaging




Present
2018-2020
2020s
SAR Systems used for geodetic imaging
Sentinel-1s (C)
Sentinel-1 NG (C/L?)
ALOS-4 (L)
ALOS-2 (L)
- Open raw/SLC data access
- Global high area coverage rate
RADARSAT2 (C)
SAOCOM1-A/B (L)
TerraSARs (X)
RCM (C)
NISAR (L/S)
COSMO-SkyMeds (X)
CSK-NG (X)
RISAT-1A (C)
Tandem-L (?)
Commercial Constellations (?)
Others...
Others...

Options for Realizing the Decadal Survey beyond NISAR

For $500M (US contribution) requires partnerships and/or disruptive approaches

1. Sentinel-1 and potentially Tandem-L as backbone of international framework – Supplement with other SAR data
   - NASA comparable capability
     - NISAR-Follow On
     - NISAR-Lite
     - Small-SAR multi-use constellation
   - International SAR data as usual
   - Commercial data buys as appropriate
2. Stand-alone geodetic constellation
   - Tailored for low cost and geodetic performance, not imaging
     - Contextual imagery supplied by other systems
   - Sufficiently low cost to fit programmatically with improved characteristics*
   - Designed with international framework in mind

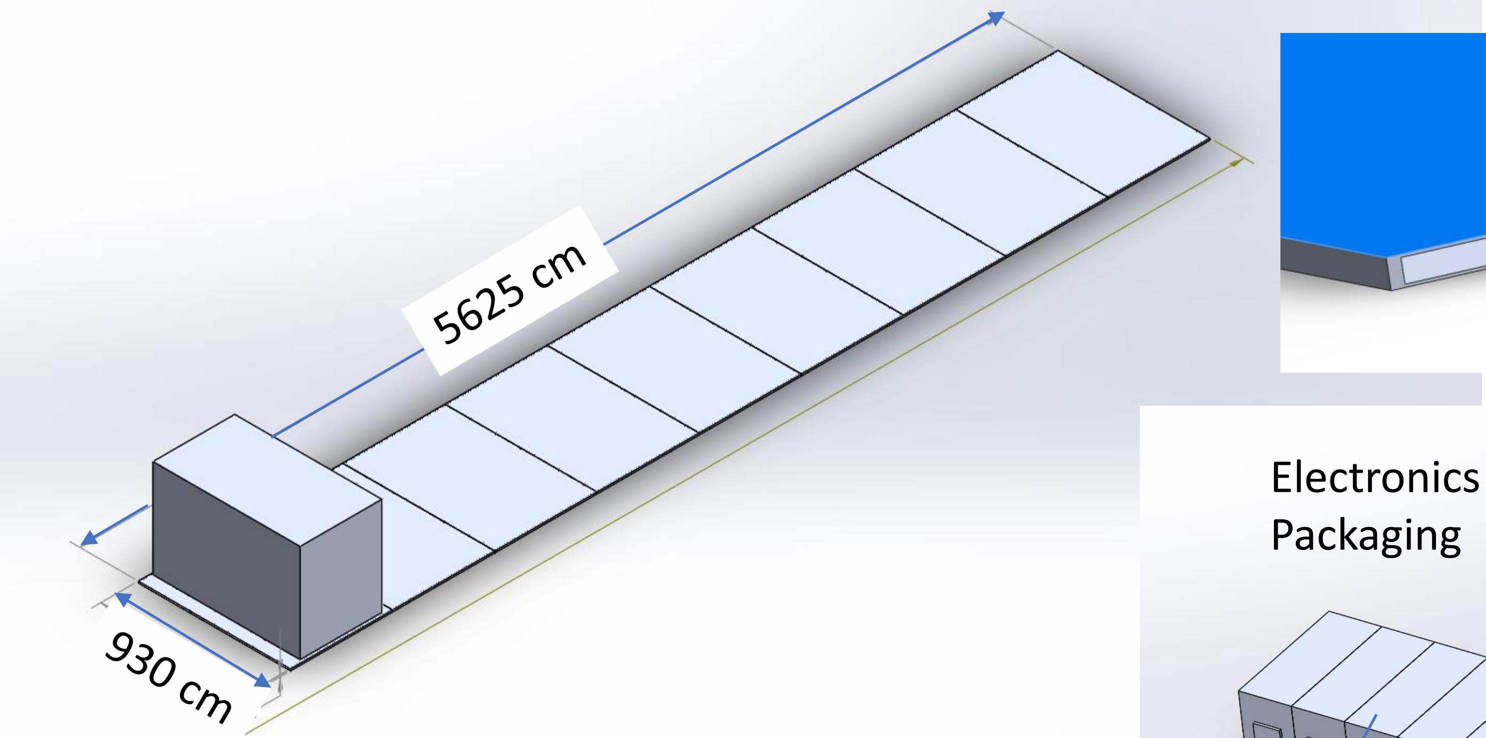
* For example, improved vector diversity, resilience to failures, upgrade path

NISAR Follow-on Ideas

1. NASA-ISRO NISAR partnership II
2. NISAR-Lite: Single-Pol, Single frequency, Single mode
   - Rebuild with minimal changes to designs
3. BYOS* imaging constellation
   - Small-SAR with nominal imaging/interferometry capabilities
   - Low cost, open architecture
   - Exploit trends in commercial cost-constrained development and operations
   - Invite partners to contribute satellites
4. BYOS* geodetic constellation
   - Small-SAR with poor imaging performance, but suitable for geodetics
   - Low cost, open architecture
   - Exploit trends in commercial cost-constrained development and operations
   - Invite partners to contribute satellites

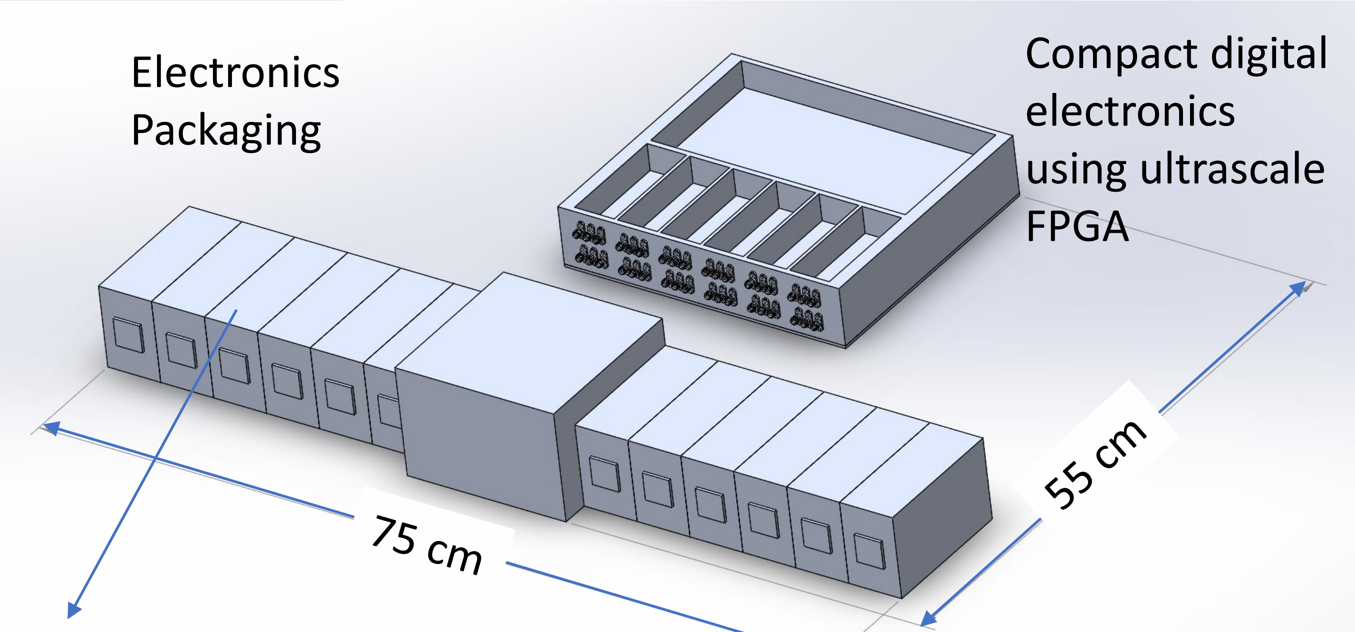
*BYOS = “Bring Your Own Satellite”

Conceptual Design elements of Small-SAR



Flat S-band 5 m x 1 m array and smallsat bus
Folds to fit Smallsat adapter ring
Commercial solutions for moderate data-rate satellite constellation downlink

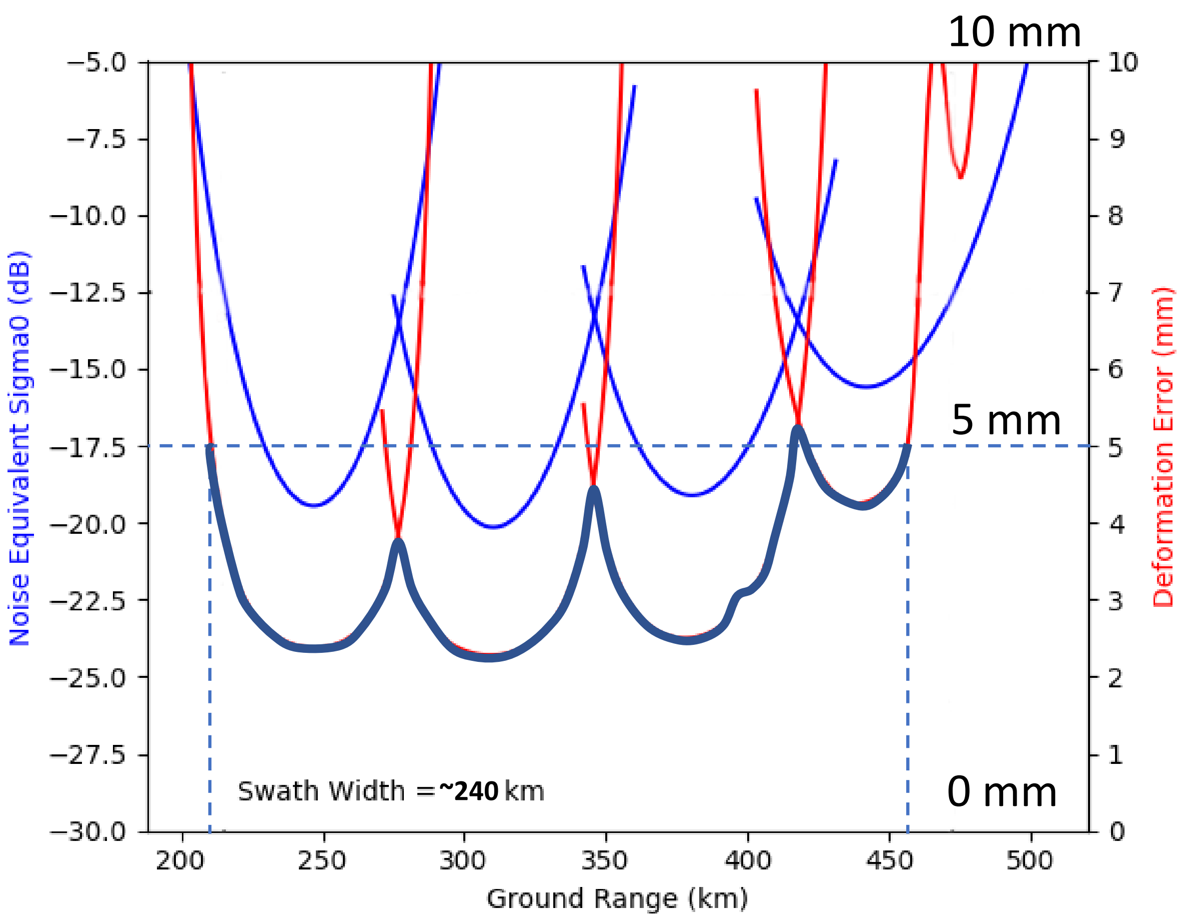
Waveguide panel – solar array on back
Routes RF signal across panels



12 T/Rs - Compact SSPA/LNA/Switch
Feeds waveguide for 12-element ScanSAR

Small-SAR Concept Performance

Effective thermal noise induced displacement error



Though imaging performance is poor in terms of planimetric resolution, radiometric resolution and accuracy, displacement performance may be adequate:

- Lower noise level than typical atmosphere
- Reasonable performance on bright targets
- Dense time-series can mitigate noise through averaging

Displacement error assumes:

- S-band soil backscatter
- 50 m resolution (8-12 looks)
- No temporal, geometric, volumetric decorrelation
- No atmosphere/ionosphere

Technology Needs

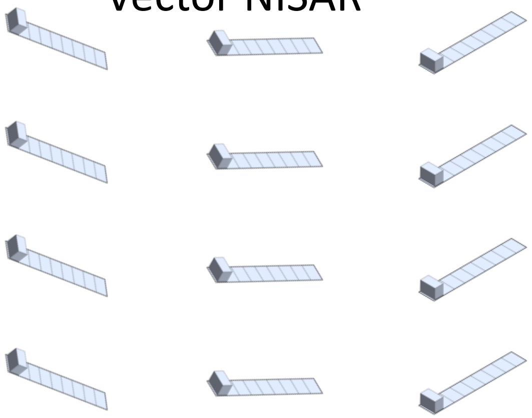
- High Aspect Ratio Deployable Antennas
  - > 5 m^2 effective aperture area for SAR data
  - > 4:1 aspect ratio in order to get wide swath
  - Stows within an ESPA or ESPA-grande class payload
- Digital Signal Processing
  - Ultrascale+ FPGAs for space reduce power and increase resources
  - Utilizing high data rate IOs to eliminate frequency converter and waveform generator hardware
- Formation Flying
  - Must maintain multiple sets of satellites within an orbit tube
  - Must also maintain along-track timing during ScanSAR operation
- High Power Integration
  - Combine SSPA, LNA, and high power switch in a single package to fit 12 channels within instrument allocated volume
  - Thermal management of 1 kW peak Tx power on microsat bus

*and as a bonus: Possible “game-changing” atmospheric mitigation

NISAR

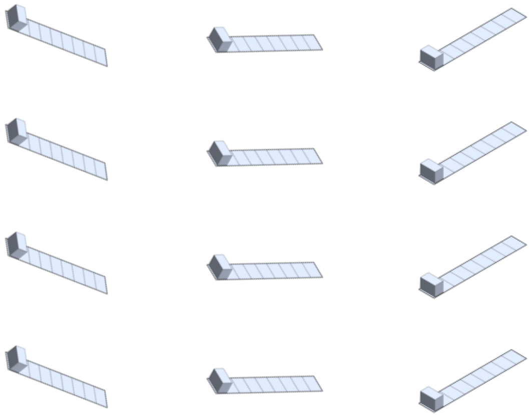
- 12 m reflector
- 2 m L+S-band feed
- **240 km SweepSAR Swath**
- 12 day repeat
- L-band Global
- S-band 10% duty
- Imaging
- Interferometry
- Polarimetry
- NESO < -25 dB

Geodetic Constellation 1
Vector NISAR*



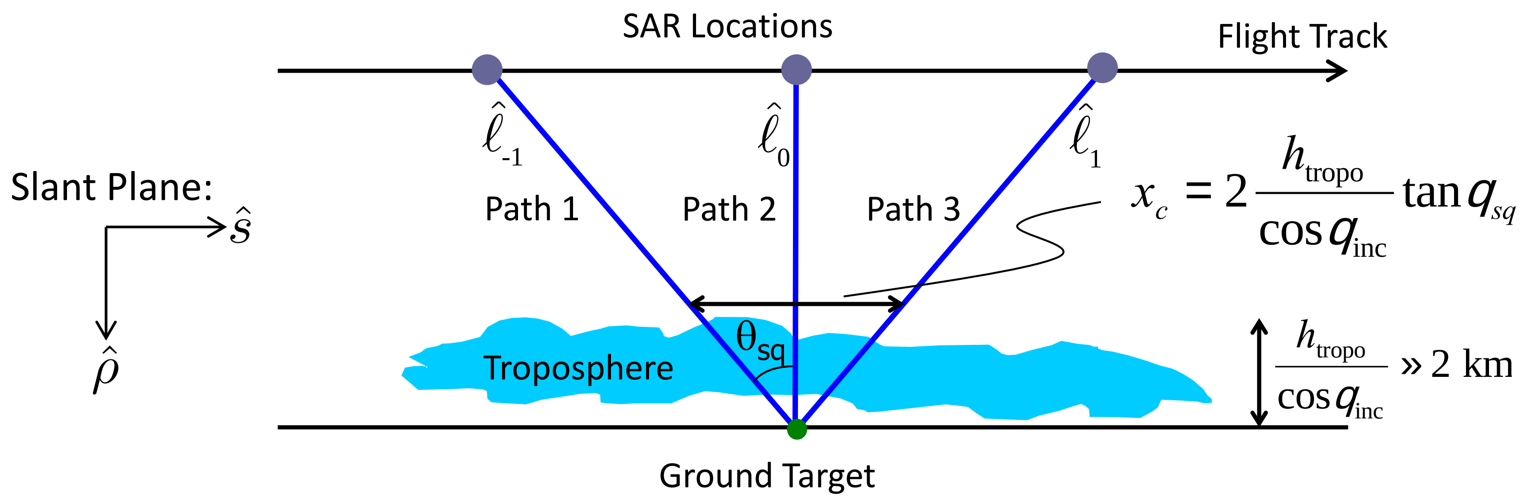
- **60 km StripSAR Swath per satellite**
- S-band Global
- Interferometry
- NESO < -12 dB
- Three satellites co-flying with fixed vector pointing offsets
- 12 satellites gives **12-day** max revisit

Geodetic Constellation 2
Vector 3X NISAR*



- **240 km ScanSAR Swath per satellite**
- S-band Global
- Interferometry
- NESO < -12 dB
- Three satellites co-flying with fixed vector pointing offsets
- 12 satellites gives **3-day** max revisit

Possible benefit of vector diversity: estimating km-scale tropospheric delay would strip away the largest error source from measurement



- Troposphere is extended in height above surface, so different signal propagation paths experience different delays
- Estimate low-spatial-frequency components with multi-squint technique, inverting

$$\vec{\phi} = \frac{4\pi}{\lambda} A\vec{D} \quad \text{where} \quad A = \begin{bmatrix} \cos\theta_{sq} & -\sin\theta_{sq} & \frac{1}{\cos\theta_{sq}} \\ 1 & 0 & 1 \\ \cos\theta_{sq} & \sin\theta_{sq} & \frac{1}{\cos\theta_{sq}} \end{bmatrix}$$

$$\vec{D} = \begin{bmatrix} d_\rho & d_s & \Delta\rho_{atm} \end{bmatrix}$$

Interferometric phase

$$\phi_i = \frac{4\pi}{\lambda}\left[\langle \vec{d}, \hat{\ell}_i\rangle + \frac{\Delta\rho_{atm}}{cos\theta_{sq}}\right]$$

where

$$\vec{d} = \begin{bmatrix} d_\rho & d_s & d_\perp \end{bmatrix}$$

is vector displacement,

$$\hat{\ell}_{-1} = \cos\theta_{sq}\hat{\rho} - \sin\theta_{sq}\hat{s}$$
$$\hat{\ell}_0 = \hat{\rho}$$
$$\hat{\ell}_1 = \cos\theta_{sq}\hat{\rho} + \sin\theta_{sq}\hat{s}$$

are 3 look vectors

Questions:

- Is geodesy without imaging attractive?
- Can we imagine a multinational coordinated spacecraft effort in this area?
- What are the partnership possibilities?
  - Common architectures?
  - Technology development?
  - Formation flying?
- What is the role of commercial providers?